WOLD

Design of A Plain Concrete Arch

Civil Engineering

B. S.

1913

# DESIGN OF
# A PLAIN CONCRETE ARCH

BY

CHARLES ABRAHAM WOLD

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## THESIS

FOR

DEGREE OF BACHELOR OF SCIENCE

IN

CIVIL ENGINEERING

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COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

1913

UNIVERSITY OF ILLINOIS

College of Engineering

May 24, 1913.

I recommend that the thesis prepared under my supervision by CHARLES ABRAHAM WOLD entitled Design of a Plain Concrete Arch be approved as fulfilling this part of the requirements for the degree of Bachelor of Science in Civil Engineering.

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Recommendation approved

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Head of Department of

Civil Engineering.

# DESIGN OF A PLAIN CONCRETE ARCH.

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## I. INTRODUCTION.

The author has chosen for his thesis the design of a plain concrete arch because he is especially interested in concrete, and because the prescribed course in civil engineering does not include the theory of the concrete arch. He feels that the concrete arch, in the future, is to be one of the principle forms of bridge construction, and especially will this be true in highway work and all places that require a structure which has a good appearance. For these reasons the author feels that the young graduate should be perfectly familiar with the theory of the arch and also be able to design an arch intelligently. He has chosen a plain concrete arch as the theory embodied is characteristic of all monolithic arches, whether reinforced or not; and as it is the authors purpose in this thesis to understand the theory and to apply it in a design, he believes that the plain concrete arch will serve the purpose very well.

## II. LOCATION.

This arch is designed to carry the C.M.& S.P. Ry. over Russel Creek, Idaho. The bed of the stream has been cut away by the water so that now there high sloping banks on each side of the stream, as is shown in plate I. This profile is ideal for the arch-bridge form of construction, for the vertical distance from the base

of the rail to the bed of the stream can be made great enough for a sufficient rise of the crown, and the high earth-embankment at the ends of the arch will be adequate to counteract the horizontal thrust of the arch at the abutments.

### III. WATERWAY.

At the present time a steel deck girder bridge 284 feet long, spans the creek. While no data are available in regard to the waterway required, it is probable, since this is only a dry creek, that the deck girder bridge furnishes more waterway than is necessary. Also it is probable that at very long intervals an enoromous amount of waterway may be necessary to take care of the floods;but it is better to furnish a waterway only for the ordinary maximum flood and not for the greatest flood. Plate I shows the waterway provided for by the arch-bridge.

### IV. SPECIFICATIONS.

The specifications for this arch are the standard specifications of THE AMERICAN RAILWAY ENGINEERING AND MAINTENANCE OF WAY ASSOCIATION, except articles 15,16, 17, and 18.

#### Art.1. Cement.

The cement shall be portland, either American or foreign, which will meet the requirements of the standard specifications adopted by the American Society for Testing Materials.

Art. 2. Sand.

The sand shall be clean, coarse, and of grains varying in size. It shall be free from sticks and foreign matter, but it may contain clay or loom not to exceed five per cent. Crusher dust, screened to reject all particles over one quarter inch in diameter, may be used instead of sand, if approved by the engineer.

Art. 3. Stone.

The stone shall be hard, sound and durable, crushed to sizes not to exceed two inches in any direction.

Art. 4. Gravel.

The gravel shall be composed of clean pebbles of hard and durable stone of sizes not exceeding two inches in diameter, free from clay and other impurities except sand.

Art. 5. Water.

The water shall be clean and reasonably clear, free from sulphuric acid or strong alkalies.

Art. 6. Mixing.

A machine mixer shall be used whenever the volume of the work will justify the expense of installing the plant. The necessary requirements for the machine shall be that a precise and regular proportioning of the materials can be controlled, and the product as delivered shall be of the required consistency and be thoroughly mixed.

If hand mixed, tight platforms shall be provided of sufficient size to accommodate the men and materials for the progressive and rapid mixing of at least two batches of concrete at the same time. Batches shall not exceed one cubic yard each, and smaller batches are preferable, based upon a multiple of number of sacks to the barrel.

The sand shall be spread evenly upon the platform, then the cement upon the sand, and mixed thoroughly until of an even color. Add all the water necessary to make a thin mortar, and spread again; add the gravel, if used, and finally the broken stone, both of which, if dry, should be thoroughly wet down. Turn the mass over with shovels or hoes until thoroughly incorporated, and until all the gravel and stone is covered with mortar, which will probably require the mass to be turned four times.

Art. 7. Consistency.

The concrete shall be of such consistency that when dumped in place it will not require much tamping. It shall be spaded down, and sufficiently tamped to level it off, after which the water should rise freely to the surface.

Art. 8. Forms.

(a) Forms shall be well built, substantial and unyielding, properly braced or tied together by means of wire or rods, and shall conform to the lines given.

(b) For all important work, the lumber used for face work shall be dressed on one side and both edges, and shall

be sound and free from loose knots , secured to the studdings or uprights in horizontal lines.

(c) For backing and other rough work, undressed lumber may be used.

(d) Where corners of the masonry and other projections liable to injury occure, suitable moldings shall be placed in the angles of the forms to round or bevel them off.

(e) Lumber once used in forms shall be cleaned before being used again.

. (f) The forms must not be removed within thirty-six hours after all the concrete in that section has been placed. In freezing weather, they must remain until the concrete has had a sufficient time to become thoroughly hardened.

(g) In dry but not freezing weather, the forms must be drenched with water before the concrete is placed against them.

Art. 9. Depositing.

(a) Each layer should be left somewhat rough to insure bonding with the next layer above; and if the concrete has already set, it shall be thoroughly cleansed by scrubbing with coarse brushes and water before the next layer is placed upon it.

(b) Concrete shall be deposited in the molds in layers of such thickness and position as shall be specified by the engineer in charge. Temporary planking

shall be placed at the ends of partial layers, so that none shall run out to a thin edge. In general, excepting in the arch, all concrete must be deposited in horizontal layers of uniform thickness throughout.

(c) The work shall be carried up in sections of convenient lenght and the sections shall be completed without intermission.

(d) In no case shall the work on a section stop within 18 inches of the top.

(e) Concrete shall be placed immediately after mixing, and any having an initial set shall be rejected.

Art.10. Facing.

(a) The facing may be made by carefully working the coarse stones back from the forms by means of a shovel, bar or similar tool so as to bring the excess mortar of the concrete.

(b) About one inch of mortar(not grout) of the same proportions as used in the concrete may be placed next to the forms immediately in advance of the concrete, in order to secure a perfect face.

(c) Care must be taken to remove from the inside of the forms any dry mortar in order to secure a perfect face.

Art. 11. Proportions.

The proportions of the materials in the concrete shall be as specially called for by the contract, as set forth herein, upon the lines left for that purpose, the

volume to be based upon the actual cubic contents of one barrel of specified weight. The several proportions to be used are:

| Structure | Parts by Volume. | | | |
|---|---|---|---|---|
| | Cement | Sand | Gravel | Broken Stone. |
| Arch Ring | 1 | 2 | 0 | 4 |
| Foundation | 1 | 3 | 0 | 6 |
| Parapet Walls | 1 | 2 | 0 | 4 |

Art. 12. Finishing.

After the forms are removed, which should generally be as soon as possible after the concrete is sufficiently hardened, any small cavaties or openings in the face shall be neatly filled with mortar, if necessary in the opinion of the engineer. Any ridges due to cracks or joints in the lumber shall be rubbed down with a chisel or wooden float. The entire face may then be washed with a thin grout of the consistency of whitewash, mixed in the same proportions as the mortar of the concrete. The wash shall be applied with a brush. The earlier the above operations are preformed the better will be the results.

Art 13. Waterproofing.

Where waterproofing is required, a thin coat of mortar or grout shall be applied for afinishing coat, upon which shall be placed a covering of suitable waterproofing material.

Art. 14. Freezing Weather.

Ordinarily concrete to be left above the surface of the ground shall not be constructed in freezing weather. Portland cement concrete may be built under these conditions. In this case the sand, water, and broken stone shall be heated; and in severe cold, salt shall be added in the proportion of about 2 pounds per cubic yard.

Art. 15. Loading.

The arch shall be designed to carry the dead load over the entire span and the live load over one half the span. The dead load to consist of the earth fill and the concrete, earth fill to be taken 100, and the concrete 150 lbs.per cu.ft. The live load shall be Cooper's equivalent uniform E-50 loading.

Art. 16. Stresses.

The maximum compressive stress in mass concrete 2 feet square or more shall not exceed 700 lbs.per sq. In. for 1-2-4 mixture.

Art. 17. Temperature.

The temperature stresses shall be computed for a change of 20 degrees.

Art. 18. Depth of Ballast at Crown.

A depth of three feet of earth or ballast shall cover the crown of the arch so as to distribute the live load uniformly upon the arch.

## V. PRELIMINARY DESIGN.

### Art. 19. Assumed Dimensions of Arch.

In assuming the preliminary dimensions of this arch a number of arches that have been built and have proven satisfactory were referred to. The dimensions were then chosen, with due regard to what the author considers the best designs, as follows: Span of the intrados 175 feet; rise of the intrados 38 feet and 2 inches; thickness at the crown 4 feet; thickness at the springing, in line of the radius of the neutral line, 8 feet.

### Art. 20. Investigation of Preliminary Design.

A depth of three feet of earth was placed over the extrados at the crown so as to distribute the live load uniformly upon the arch. The investigation was then made with the following loading upon the arch: The dead load consisting of the earth-fill and the concrete in the arch ring taken at 100, 150 pounds per cubic foot; the live load taken at 6,000 pounds per lineal foot of track, which is Cooper's equivalent uniform E-50 loading for a 175 feet span, covering one half the span.

With the above loading, the line of pressure fell below the middle third at the crown and springing line. On account of this condition no stresses were computed as the essential requirement in the design is not fulfilled.

## VI. FINAL DESIGN.

### Art. 21. Dimensions of the Arch.

As the line of pressure followed the lower side of the middle third, the arch was increased, on the side of the intrados, to 6 feet at the crown and to 9 feet 6 inches at the springing line. For complete dimensions of the arch see Plate V.

### Art. 22. Investigation of the Arch.

The loadings are taken the same as on the preliminary arch; three feet of earth covering the extrados of the arch at the crown. The dead load consisting of the earth-fill and the concrete in the arch ring is taken at 100, and 150 pounds per cubic foot. The live load is taken at 6,000 pounds per lineal foot of track covering one half the span.

In this case the line of pressure is found to follow well within the middle third of the arch ring, which fulfills the essential requirement of the design.

A complete solution of the arch and the stresses in the concrete are given in Plates I and II, and Tables I to IV. The maximum stresses, including the temperature stresses, which are very small and are neglected in most cases, are found to be below the allowable.

The method of working out this arch is taken from Baker's "Masonry Construction", in fact his method is followed exactly.

## VII. FOUNDATIONS.

### Art. 23. Design of Foundations.

There is no available data in regard to the bearing power of the soil, and so it is assumed to be 2.5 tons per square foot. Plate IV shows the method of design as well as the final design.

The pressure upon the soil due to dead and live load is 6.7 tons per square foot which is far above the allowable, and so concrete piling placed three feet between centers is used to bring the bearing pressure to the allowable. See Plate IV for computations.

## VIII. COST.

### Art 24. Cost of Concrete in Place Including Forms.

As it is the purpose of the author to understand the theory of the concrete arch and to apply it in a design, very little attention is paid to the estimate of cost, However, it seems well to include the number of cubic yards of concrete used in the design, and the cost of this concrete in place and also the cost of the forms.

In estimating the cost of the concrete an effort has been made to obtain an average value for concrete in place. This is also true for the cost of the forms, which is based on the number of cubic yards of concrete. See Table VI for the estimate of cost.

## IX. CONCLUSION.

This arch, while it is safe, and an economical design for a plain concrete structure, would probably never be built, since with such a long span and heavy loading any plain concrete structure must necessarly be very heavy in order to keep the stresses within the allowable limit. It is almost certain, if a concrete arch was used at all, that it would be of the reinforced type; but it is the opinion of the author that the present plate deck girder is a much more economical design than either the plain or reinforced concrete arch designs.

## TABLE I.

### DATA FOR MAKING $\Delta S/I$ CONSTANT.

| Ref. Point. | Depth of of Arch at Point. in Ft. | $I = bd^3/12$ | Point on Neutral Axis of Arch Ring $\Delta S$ in Length. | Length of Section $\Delta S$. in Ft. | I at Center of $\Delta S$. | $\Delta S/I. = C$ |
|---|---|---|---|---|---|---|
| 0. | 6.00 | 18.0 | a1. | | | |
| 1. | 6.03 | 18.6 | a2. | 20.85 | 76.1 | .274 |
| 2. | 6.11 | 19.1 | a3. | 13.70 | 50.5 | .274 |
| 3. | 6.28 | 20.8 | a4. | 10.38 | 37.9 | .274 |
| 4. | 6.55 | 23.4 | a5. | 8.50 | 30.9 | .275 |
| 5. | 6.88 | 27.1 | a6. | 7.35 | 26.8 | .274 |
| 6. | 7.25 | 31.9 | a7. | 6.50 | 23.8 | .273 |
| 7. | 7.73 | 38.4 | a8. | 5.95 | 21.8 | .273 |
| 8. | 8.23 | 46.6 | a9. | 5.55 | 20.3 | .274 |
| 9. | 8.78 | 56.8 | a10. | 5.25 | 19.15 | .274 |
| 10. | 9.35 | 70.1 | a11. | 5.05 | 18.5 | .273 |
| 11. | 10.1 | 85.8 | a12. | 5.00 | 18.1 | .275 |
| 12. | | | a13. | 4.90 | 18.0 | .273 |

## TABLE II .

### DATA FOR FINDING THE TRUE EQUILIBRIUM POLYGON.

| Points | Neutral Line of Arch Ring. | | Trial Equilibrium Polygon. | | | |
|---|---|---|---|---|---|---|
| | Cor. From Center of Span Line. | | Intercepts. | | Products. | |
| | x | y | $b \cdot v$ | $n_{,}F'v_{,} = f$ | $bv \cdot x$ | $f \cdot x$ |
| a1. | -93.20 | 0.00 | 0.00 | 15.80 | | -1,471.0 |
| a2. | -84.55 | 5.48 | 4.73 | 14.32 | -400.00 | -1,211.0 |
| a3. | -69.10 | 13.43 | 11.31 | 11.71 | -782.00 | - 810.0 |
| a4. | -57.88 | 18.05 | 14.77 | 9.81 | -854.20 | - 567.5 |
| a5. | -48.95 | 21.05 | 16.89 | 8.30 | -826.50 | - 406.5 |
| a6. | -41.35 | 23.15 | 18.31 | 7.03 | -757.50 | - 291.0 |
| a7. | -34.65 | 24.75 | 19.30 | 5.90 | -669.00 | - 204.8 |
| a8. | -28.55 | 25.90 | 20.05 | 4.84 | -557.80 | - 138.1 |
| a9. | -22.90 | 26.80 | 20.51 | 3.88 | -469.00 | - 88.9 |
| a10. | -17.55 | 27.45 | 20.84 | 2.98 | -366.00 | - 52.3 |
| a11. | -12.45 | 27.90 | 21.04 | 2.10 | -262.00 | - 26.2 |
| a12. | - 7.40 | 28.20 | 21.13 | 1.25 | -156.30 | - 9.2 |
| a13. | - 2.50 | 28.32 | 21.12 | 0.40 | - 52.80 | - 0.1 |
| Crown | | | | | | |
| a14. | + 2.50 | 28.32 | 21.02 | | + 52.60 | |
| a15. | + 7.40 | 28.20 | 20.82 | | +154.20 | |
| a16. | +12.45 | 27.90 | 20.55 | | +255.90 | |
| a17. | +17.55 | 27.45 | 20.18 | | +354.00 | |
| a18. | +22.90 | 26.80 | 19.71 | | +452.00 | |
| a19. | +28.55 | 25.90 | 19.10 | | +545.20 | |
| a20. | +34.65 | 24.75 | 18.33 | | +636.50 | |
| a21. | +41.35 | 23.15 | 17.30 | | +715.00 | |
| a22. | +48.95 | 21.05 | 15.87 | | +776.00 | |
| a23. | +57.88 | 18.05 | 13.82 | | +800.00 | |
| a24. | +69.10 | 13.43 | 10.52 | | +651.50 | |
| a25. | +84.55 | 5.48 | 4.30 | | +364.00 | |
| a26. | +93.20 | 0.00 | 0.00 | | | |
| | | 540.96 | 411.52 | | -395.00 | -5,276.6 |

TABLE II. (Cont.)

DATA FOR FINDING THE TRUE EQUILIBRIUM POLYGON.

| Points. | True Equilibrium Polygon. | | | | $bm \frac{\Sigma ak \cdot y}{\Sigma bm \cdot y}$ |
|---|---|---|---|---|---|
| | Intercepts. | | Products. | | |
| | b m | a k | bm·y | ak·y | = c k |
| a1. | +16.40 | +10.40 | 0.00 | 0.00 | + 11.10 |
| a2. | +11.63 | + 7.68 | + 64.80 | +42.20 | + 7.87 |
| a3. | + 4.94 | + 3.66 | + 66.40 | +49.20 | + 3.35 |
| a4. | + 1.42 | + 1.37 | + 25.60 | +24.75 | + 0.96 |
| a5. | − 0.76 | − 0.12 | − 16.00 | − 2.52 | − 0.51 |
| a6. | − 2.22 | − 1.20 | − 51.40 | − 27.80 | − 1.50 |
| a7. | − 3.25 | − 1.98 | − 80.50 | − 49.00 | − 2.20 |
| a8. | − 4.01 | − 2.58 | − 104.10 | − 66.80 | − 2.72 |
| a9. | − 4.52 | − 3.01 | − 121.00 | − 80.50 | − 3.06 |
| a10. | − 4.91 | − 3.35 | − 134.80 | − 92.00 | − 3.32 |
| a11. | − 5.14 | − 3.57 | − 143.40 | − 99.60 | − 3.48 |
| a12. | − 5.27 | − 3.71 | − 148.70 | −104.60 | − 3.57 |
| a13. | − 5.30 | − 3.78 | − 150.00 | −107.00 | − 3.59 |
| Crown | | | | | |
| a14. | − 5.23 | − 3.78 | − 148.10 | | − 3.54 |
| a15. | − 5.08 | − 3.71 | − 143.50 | | − 3.44 |
| a16. | − 4.82 | − 3.57 | − 134.20 | | − 3.26 |
| a17. | − 4.51 | − 3.35 | − 123.90 | | − 3.06 |
| a18. | − 4.07 | − 3.01 | − 109.00 | | − 2.76 |
| a19. | − 3.49 | − 2.58 | − 90.40 | | − 2.35 |
| a20. | − 2.75 | − 1.98 | − 68.10 | | − 1.86 |
| a21. | − 1.77 | − 1.20 | − 41.00 | | − 1.20 |
| a22. | − 0.38 | − 0.12 | − 7.98 | | − 0.26 |
| a23. | + 1.57 | + 1.37 | + 28.30 | | + 1.06 |
| a24. | + 4.82 | + 3.66 | + 64.70 | | + 3.27 |
| a25. | +10.82 | + 7.68 | + 59.40 | | + 7.35 |
| a26. | +15.20 | +10.40 | 0.00 | | +10.30 |
| | − 0.68 | − 0.26 | + 1516.88 | | − 0.49 |

COMPUTATIONS FOR FINDING THE TRUE EQUILIBRIUM POLYGON AND THE TRUE POLE DISTANCE.

$$X_l = \frac{2 \cdot f \cdot x}{R} = 25.7$$

$$X_l = X_r = 25.7$$

$$v_1 m_1 = \frac{25.7 - 0.96}{25.7} 15.80 = 16.40$$

$$v_{26} m_{26} \quad \frac{25.7 - 0.96}{25.7} 15.80 = 15.2$$

$$\frac{\Sigma a\ k \cdot y}{\Sigma b\ m \cdot y} = \frac{1,027.34}{1,516.88} = 0.6775$$

$$\text{True Pole Distance} = \text{Trial Pole Distance} \times \frac{\Sigma b\ m\ y}{\Sigma a\ k\ y}$$

$$200,000 \times \frac{1}{0.6775} = 295,000$$

TABLE III.

DEAD AND LIVE LOAD STRESSES.

+ Signifies Compression; — Signifies Tension.

| Ref. Point. | Depth of Arch at Point in Ft. | ac at Point. in Ft. | Thrust at Point. in 1000. lbs. | Stresses Due To Dead And Live Loads. | | | |
|---|---|---|---|---|---|---|---|
| | | | | Bending. | | Thrust. | |
| | | | | lbs.per sq. ft. | lbs.per sq. In. | lbs.per sq.ft. | lbs.per sq. In. |
| a2. | 8.90 | 0.38 | 343.0 | ±8,470 | ± 58.8 | +38,500 | +267.1 |
| a3. | 7.95 | 0.62 | 326.5 | ±17,390 | ±120.5 | +41,200 | +284.2 |
| a4. | 7.40 | 0.80 | 314.8 | ±25,400 | ±176.1 | +42,500 | +295.3 |
| a5. | 7.00 | 0.78 | 307.8 | ±28,200 | ±195.5 | +43,700 | +304.0 |
| a6. | 6.70 | 0.60 | 306.0 | ±23,600 | ±163.5 | +45,600 | +306.1 |
| a7. | 6.50 | 0.44 | 300.0 | ±18,400 | ±127.8 | +46,100 | +320.0 |
| a10. | 6.15 | 0.06 | 296.0 | ±2,840 | ± 19.7 | +48,200 | +334.0 |
| a13. | 6.05 | 0.38 | 295.3 | ±18,300 | ±127.0 | +48,700 | +338.2 |
| a15. | 6.05 | 0.54 | 295.7 | ±26,100 | ±181.0 | +48,700 | +339.0 |
| a16. | 6.10 | 0.61 | 296.0 | ±28,900 | ±200.0 | +48,500 | +337.3 |
| a19. | 6.35 | 0.46 | 300.0 | ±20,200 | ±140.5 | +47,500 | +328.0 |
| a22. | 7.00 | 0.34 | 313.0 | ±12,250 | ± 86.5 | +44,700 | +310.0 |
| a25. | 8.90 | 0.66 | 353.0 | ±14,750 | ±103.7 | +39,600 | +275.0 |

TABLE IV.

TEMPERATURE STRESSES.

+ Signifies Compression; — Signifies Tension.

| Ref. Point. | $Q = \frac{E l e t}{\Sigma a k \cdot y} \times \frac{S}{I}$ | Temperature Stresses for a Change of 20 Degrees. | | | |
|---|---|---|---|---|---|
| | | Bending. | | Thrust. | |
| | | lbs.per. sq. ft. | lbs.per sq. In. | lbs.per sq. ft. | lbs.per sq. In. |
| a2. | 7,760 | ± 2,240 | ± 1.6 | + 872 | + 6.1 |
| a3. | " | ± 4,570 | ± 3.2 | + 975 | + 6.8 |
| a4. | " | ± 6,820 | ± 4.7 | + 1,550 | + 7,3 |
| a5. | " | ± 7,420 | ± 5.2 | + 1,110 | + 7.7 |
| a6. | " | ± 6,320 | ± 4.2 | + 1,160 | + 8.0 |
| a7. | " | ± 4,850 | ± 3.4 | + 1,190 | + 8.3 |
| a10. | " | ± 7,280 | ± 5.1 | + 1,260 | + 8.7 |
| a13. | " | ± 4,820 | ± 3.3 | + 1,280 | + 8.9 |
| a15. | " | ± 6,860 | ± 4.8 | + 1,280 | + 8.9 |
| a16. | " | ± 7,640 | ± 5.3 | + 1,270 | + 8.8 |
| a19. | " | ± 5,320 | ± 3.7 | + 1,220 | + 8.5 |
| a22. | " | ± 3,320 | ± 2.2 | + 1,110 | + 7.7 |
| a25. | " | ± 3,880 | ± 2.7 | + 870 | + 6.0 |

# TABLE V.

## MAXIMUM STRESSES IN CONCRETE.

+ Signifies Compression; _ Signifies Tension.

| Points | Dead and Live Load Stresses. | | Temperature Stresses. | | Maximum Stresses. | |
|---|---|---|---|---|---|---|
| | Bending lbs.per sq. In. | Thrust lbs. per sq. In. | Bending lbs.per sq. In. | Thrust lbs.per sq. In. | Extrados lbs.per sq. In. | Intrados lbs.per sq. In. |
| a2. | ± 58.8 | +267.1 | ± 1.6 | + 6.1 | +212.8 | +333.6 |
| "3. | ±120.5 | +284.2 | ± 3.2 | + 6.8 | +414.7 | +167.3 |
| "4. | ±176.1 | +289.3 | ± 4.7 | + 7.3 | +477.4 | +115.8 |
| "5. | ±195.5 | +304.0 | ± 5.2 | + 7.7 | +512.4 | +111.0 |
| "6. | ±163.5 | +306.1 | ± 4.2 | + 8.0 | +481.8 | +146.4 |
| "7. | ±127.8 | +320.0 | ± 3.4 | + 8.3 | +459.5 | +197.1 |
| a10. | ± 19.7 | +334.0 | ± 5.1 | + 8.7 | +317.9 | +367.5 |
| "13. | ±127.0 | +338.2 | ± 3.3 | + 8.9 | +216.6 | +477.2 |
| "15. | ±191.0 | +339.0 | ± 4.8 | + 8.9 | +152.1 | +543.7 |
| "16. | ±200.2 | +337.3 | ± 5.3 | + 8.8 | +140.6 | +551.6 |
| "19. | ±140.5 | +328.0 | ± 3.7 | + 8.5 | +192.3 | +480.7 |
| "22. | ± 86.7 | +310.1 | ± 2.2 | + 7.7 | +406.7 | +228.9 |
| "25. | ±103.0 | +275.0 | ± 2.7 | + 6.0 | +406.7 | +175.3 |

TABLE VI.

CUBIC YARDS OF CONCRETE AND ESTIMATE OF COST.

| Structure | Cu. Yds. of Concrete | Cost per Cu.Yd. in Place | Cost of Forms Based on Cu.Yds. Concrete | Totals. |
|---|---|---|---|---|
| Arch Ring | 889.7 | $12.00 | $1.75 | $12,233.38 |
| Abutments | 706.2 | 9.00 | .25 | 6,532.35 |
| Parapet Walls | 31.1 | 12.00 | 1.90 | 432.29 |
| Totals. | 1627.0 | | | $19,198.02 |

PLATE I

PROFILE AND POSITION OF ARCH

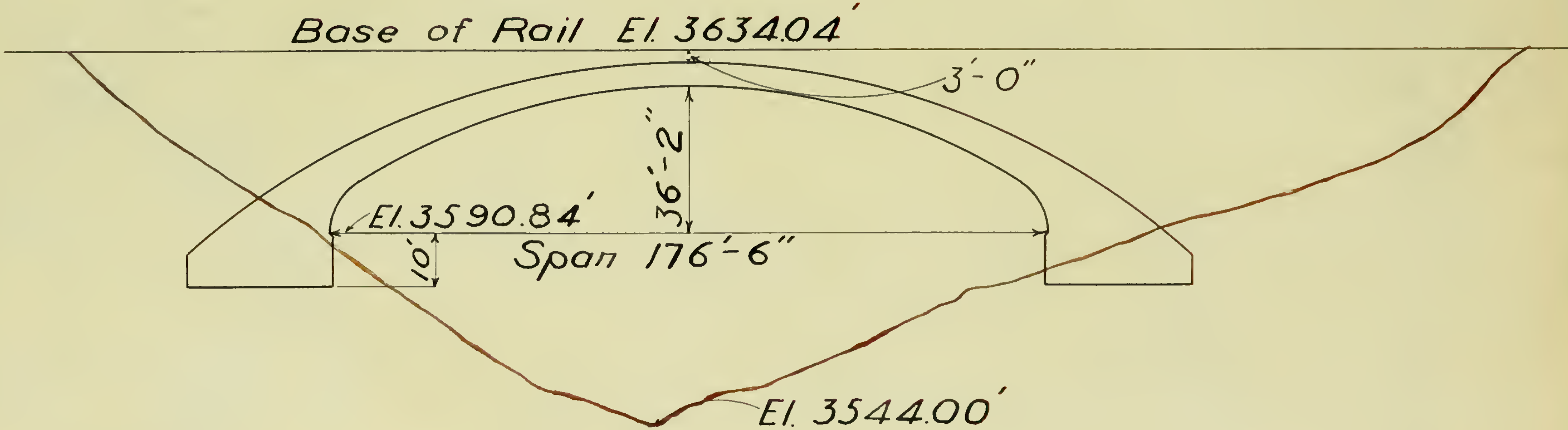
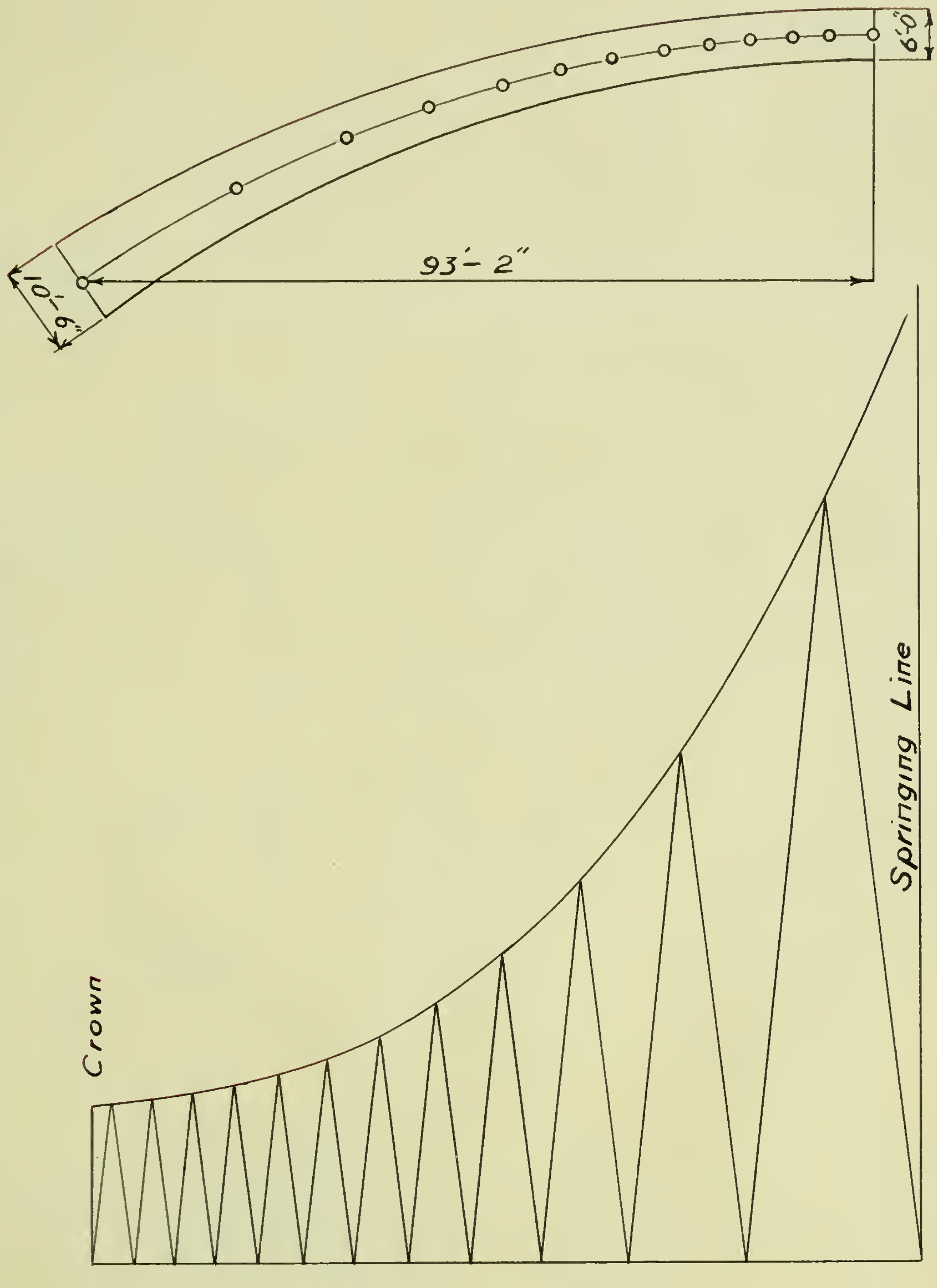


PLATE II

DRAWING OF ΔS ÷ I CONSTANT



| | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Concrete | 12000 | 15500 | 13800 | 12200 | 10700 | 8100 | 7500 | 5940 | 5380 | 5120 | 4740 | 4570 | 4560 | 4500 | 4560 | 4570 | 4740 | 5120 | 5380 | 5940 | 7500 | 8100 | 10700 | 12200 | 13800 | 15500 | 12000 |
| Earth | 26300 | 19500 | 16700 | 13100 | 9700 | 6400 | 4600 | 3300 | 2600 | 2200 | 1800 | 1600 | 1500 | 1400 | 1500 | 1600 | 1800 | 2200 | 2600 | 3300 | 4600 | 6400 | 9700 | 13100 | 16700 | 19500 | 26300 |
| Live Load | 4200 | 4200 | 4200 | 4200 | 3900 | 3300 | 2900 | 2700 | 2400 | 2300 | 2250 | 2200 | 2150 | 2100 | | | | | | | | | | | | | |
| Total Load | 42500 | 39200 | 34700 | 29500 | 23500 | 17800 | 14000 | 11900 | 10300 | 9620 | 8790 | 8370 | 8210 | 8300 | 6060 | 6170 | 6540 | 7320 | 7980 | 9240 | 12100 | 14500 | 20400 | 25300 | 30500 | 35000 | 38300 |

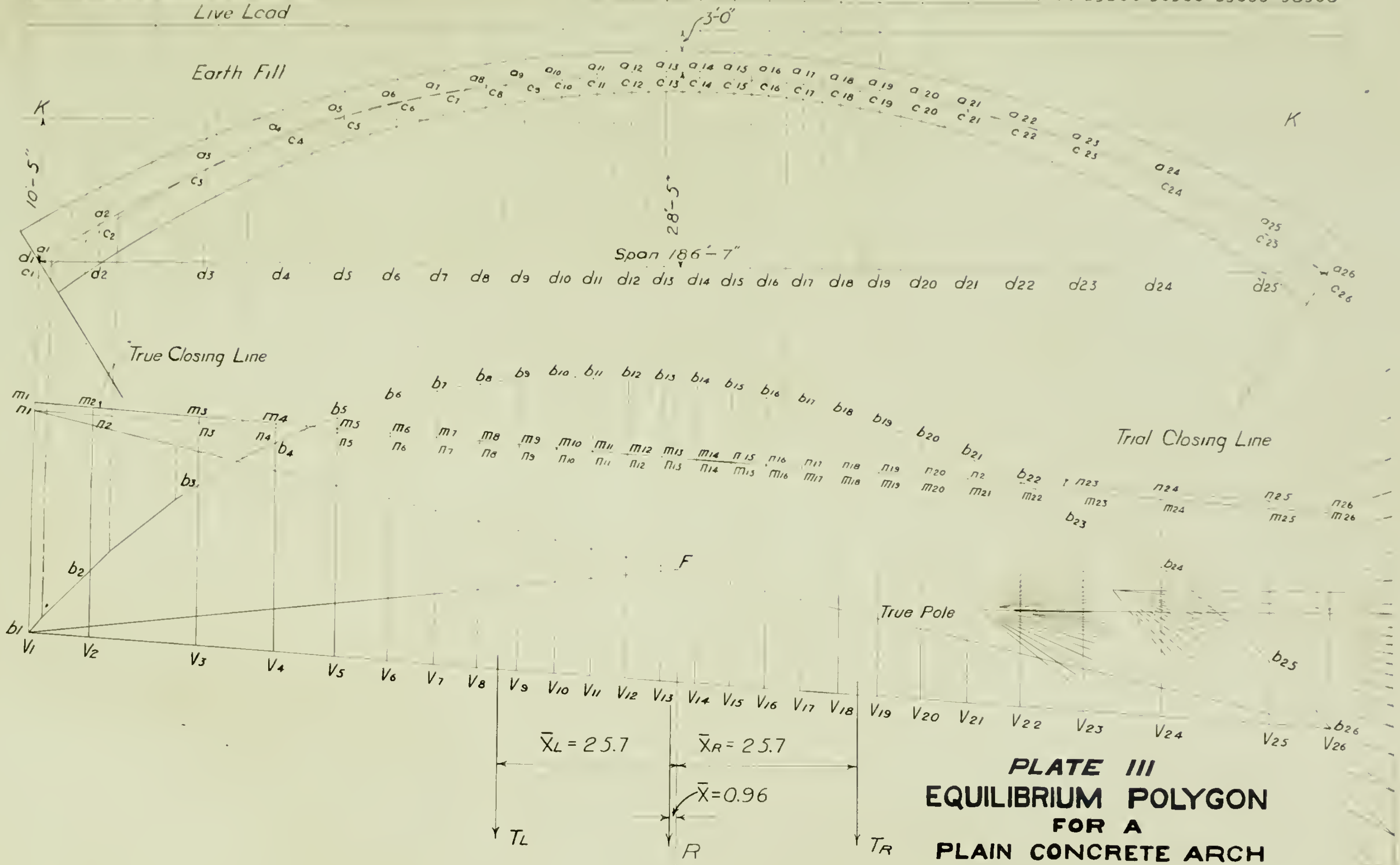



**PLATE III**

**EQUILIBRIUM POLYGON**

**FOR A**

**PLAIN CONCRETE ARCH**

*Span 176'-6" Rise 36'-3'*

*Scale 1" = 6' & 1" = 30,000#*

*Drawn By E.Q. Wold*

# PLATE IV
## ARCH FOUNDATION

A.C. = Thrust of Arch
C.F. = Weight of Abutment and earth over abutment.
C.N. = Total Pressure on soil = 480,000 lbs.
480,000 × 16 = 7,68,0,000 lbs. is pressure on foundation
7,860,000 ÷ 500 = 1536.0 □"
Area of concrete required in piles.
$\pi d^2 N \div 4 = 1536.0$
Using piles 18" in dameter
$N = 1536.0 \times 4 \div \pi \times 324$
$= 60$ piles

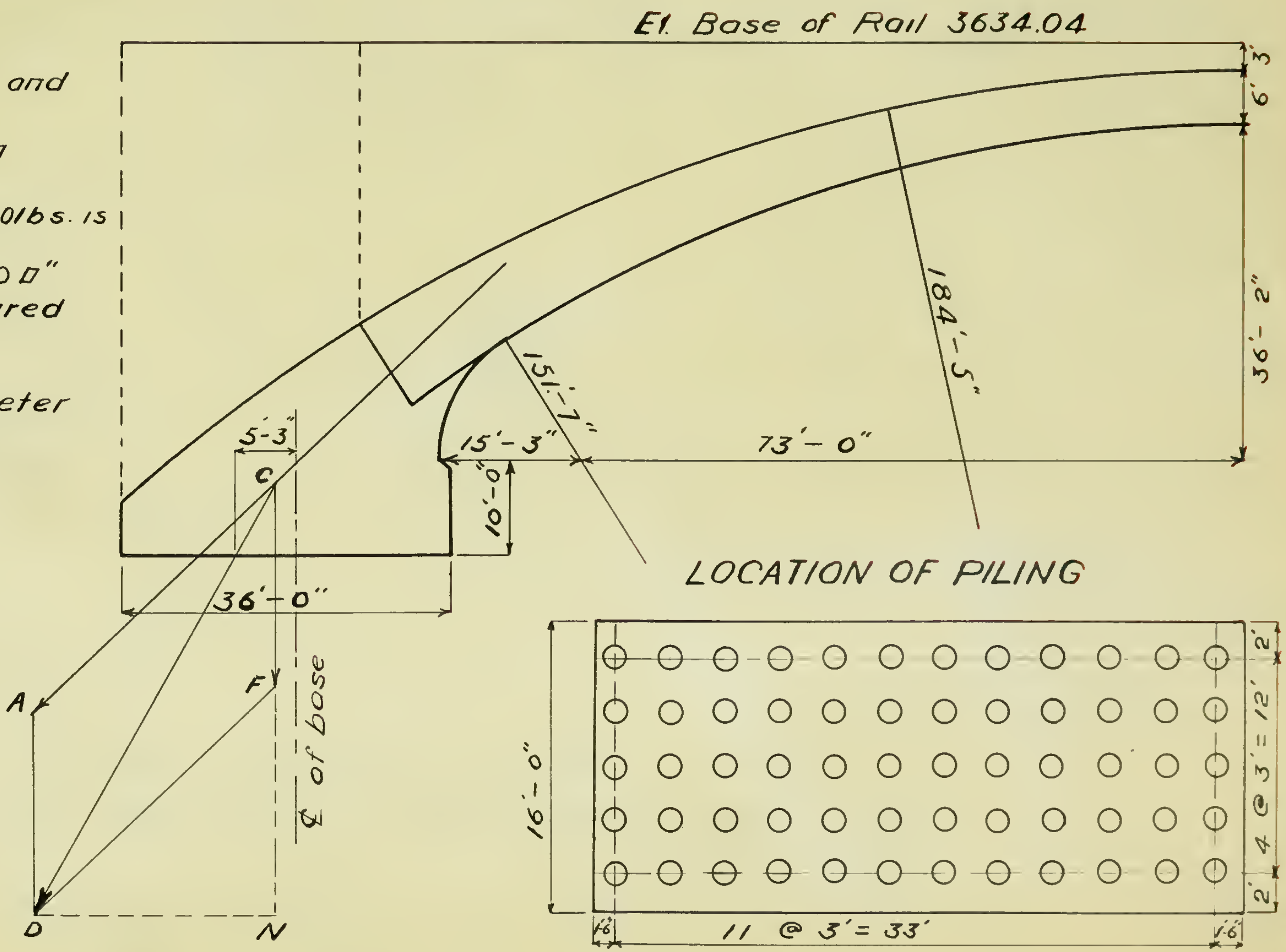
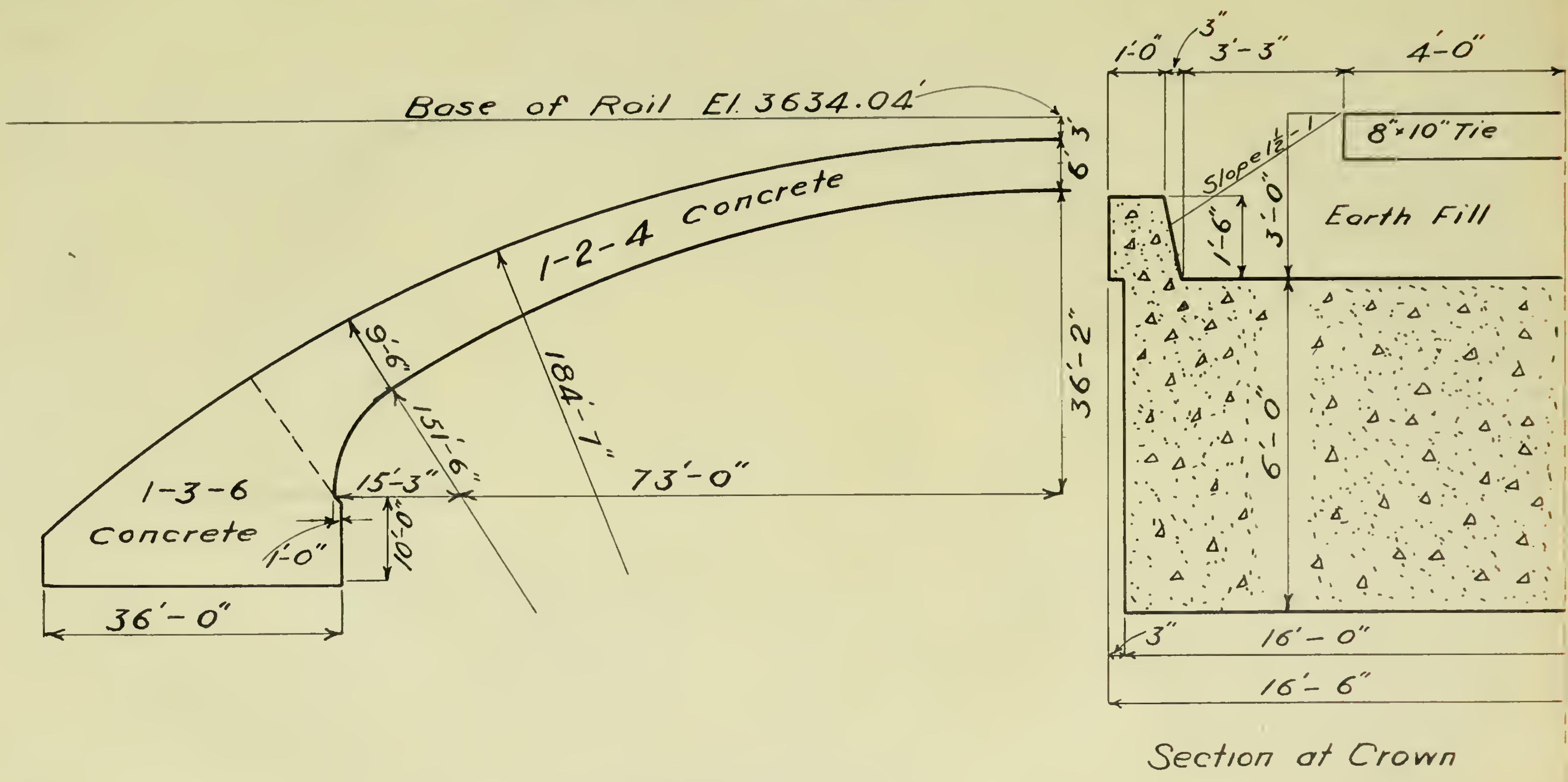


PLATE V.




PLAIN CONCRETE ARCH
AND SECTION OF ARCH RING